THE HIGH PERFORMANCE DISCONTINUOUS FIBRE (HiPerDiF) METHOD FOR CARBON-FLAX HYBRID COMPOSITES MANUFACTURING

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ABSTRACT

The composite material industry is not immune from growing environmental concerns. Two are the main solution that have been proposed so far: waste recycling and bio-based materials. The thermosetting-based composites recycling is a two-step processes: a fibre reclamation stage, where the fibres are retrieved by degrading the matrix, and a remanufacturing stage to produce a reusable material. However, independently from the process, reclaimed fibres are averagely fragmented in short length and a remanufacturing process able to achieve high fibre alignment is the key factor to deliver commercially valuable and high performance recycled composite materials. Natural fibres, e.g. bamboo, jute and hemp, are considered a valid structural alternative to synthetic fibres. In particular, flax fibre composites are lighter and cheaper than glass fibre composite with comparable specific tensile stiffness and strength. The possibility to use the HiPerDiF (High Performance Discontinuous Fibre) method to manufacture highly aligned discontinuous fibres intermingled hybrid composites with flax and reclaimed carbon fibres (rCF) is investigated in this paper. Intermingled flax/rCF hybrid composites are then characterised in terms of tensile and vibration damping response. It is concluded that natural/reclaimed fibre hybrid composite can be a viable solution for those applications where a reduction in primary properties is an acceptable trade-off for the enhancement of secondary properties and the reduction of costs.

1 INTRODUCTION

The use of composite materials in engineering applications has been constantly growing over the past years thanks to the advantages offered by their specific strength and stiffness. However, the growing concerns about environmental issues pose the challenge to develop more sustainable material sourcing and management solutions. On one hand, carbon fibre reinforced plastics (CFRP) are fully synthetic materials and require energy intensive raw material production and components manufacturing processes. On the other hand, the cross-linked nature of the thermosetting matrix makes the disposal of production and end-of-life waste extremely difficult. Two possible solutions to develop more sustainable composites are the use of natural or bio-based fibres and the implementation of effective recycling processes.

Natural fibre reinforced plastics have been used for vehicles production for more than a decade [1]. Amongst different natural fibres (e.g. hemp, jute and bamboo) the ones extracted from the flax plant are of particular interest for engineering applications [2]. Flax fibres are generally 50% lighter than glass fibres, cheaper and more environmentally friendly [3]. Flax fibre composites have specific stiffness and specific tensile strength comparable to glass fibre composites but a lower impact strength [3,4]. However, surface treatments are available to increase the poor fibre-matrix adhesion properties caused by the hydrophilic nature of flax fibres [5, 6]. On a structural point of view, the viscoelastic nature of flax fibres translates into good vibration damping properties [7].

A complete review about the technologies to recycle carbon fibre reinforced polymers for structural applications was presented by Pimenta and Pinho [8]. The recycling process of composite materials, in particular of carbon fibre reinforced thermosetting resins, can be divided in two stages: the fibre reclamation and the fibre remanufacturing to obtain an intermediate material or a finite product. Amongst the fibre reclamation processes, it is worth mentioning pyrolysis [9], oxidation in fluidised bed [10] and supercritical fluids [11]. Independently from the fibre recovery process, the size-reduction of CFRP waste before reclamation, the fibre breakage during reclamation and the chopping of the fibres after reclamation lead to fibres that are averagely fragmented in short length. As a result, the only industrially relevant remanufacturing processes for reclaimed fibres so far are direct moulding techniques [12] and the compression moulding of intermediate random or aligned mats [13]. However, to deliver improved recycled materials, a high fibre alignment is the key factor to increase the fibre volume fraction, and consequently the performances of recycled composites [14]. Various techniques, already used for the alignment of short fibres, have been taken in consideration for the remanufacturing of reclaimed carbon fibres, such as modified papermaking technique [15], centrifugal alignment rig [16] and hydrodynamic spinning process [16]. The HiPerDiF method, invented at the University of Bristol [17], has proven to be an effective way to manufacture composite materials with high levels of alignment from discontinuous fibres. It was previously noted that tensile modulus, strength and failure strain of aligned discontinuous fibre composites produced with the HiPerDiF method were close to those of continuous fibre composites provided that the fibres are accurately aligned and their length is sufficiently long compared to the critical fibre length [18, 19]. Remanufacturing reclaimed fibres with the HiPerDiF method allows on one hand the production of high performance recycled carbon fibre composites thanks to a high level of fibre alignment and on the other hand is adequate to deal with the geometric characteristics of reclaimed carbon fibres [20, 21].

It has already been proven that flax/carbon hybrid composite are an effective solution for noise, vibration and harshness (NVH) damping in automotive applications by the CARBIO project [22]. The project successfully produced an interlaminated 50/50 % carbon/flax hybrid composite that had 15% lower cost, 7% lower weight and 58% higher vibration damping compared to a pure carbon fibre composite of equivalent bending stiffness. In this paper, the HiPerDiF method is used to manufacture intermingled flax and reclaimed carbon fibres (rCF) hybrid composites and investigate their tensile and damping properties.

2 MATERIALS & MANUFACTURING

2.1 Materials

Reclaimed carbon fibres (rCF), obtained from a pyrolysis process, and flax fibres have been used. The fibres properties are summarised in Table 1, as data sheets were not provided by the manufacturers and the fibres were too short to perform single fibre tests, no further information are available. The fibres are impregnated using MTM49-3 epoxy resin.

Fibre properties		rCF	Flax
Length	[mm]	3	3
Density	[g/cm^3]	1.8	1.4
Cost	[€/kg]	8	5

Table 1: Fibres properties

The specimens were prepared by manually laying the number of plies required to achieve the desired thickness in semi-closed mould that was then placed in vacuum bag and cured in autoclave for 135 minutes at a temperature of 135°C and a pressure of 6 bar. After the curing process the specimens were removed from the mould and burrs at all edges were removed.

2.2 The HiPerDiF Method for Natural Fibres Manufacturing

In the HiPerDiF process, fibres between 1 and 12 mm in length are suspended in water, accelerated through a nozzle and directed in a gap between two parallel plates. The fibre alignment mechanism relies on a sudden momentum change of the fibre-water suspension at the impact with the plate. The fibres then fall on a conveyor stainless mesh belt where the water is removed by suction. The aligned fibre preform is dried with infrared radiation to allow the resin impregnation process. The dry aligned fibres preform is coupled with a resin film and partially impregnated through the application of heat and pressure. The process parameters, that dictates the areal weight of the dry fibre preform, and the resin film areal weight allowed producing a cured composite material with a fibre volume fraction of about 35%. A schematic of the HiPerDiF discontinuous fibre alignment machine is shown in Figure 1. Different types of fibres can be mixed in the water suspension, allowing for obtaining highly intermingled hybrid composites [19,20].

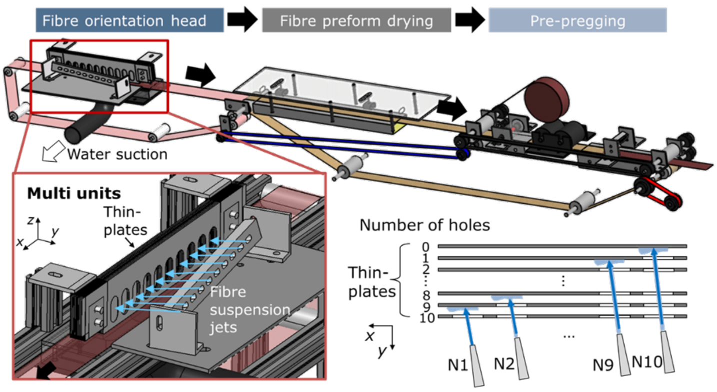

Figure 1: The HiPerDiF fibre alignment machine.

Manufacturing trials were performed to investigate the possibility to use flax fibres, that are hydrophilic, in the HiPerDiF water-based process. An amount of flax fibres, suitable to simulate the manufacturing process, was dispersed in 500 ml of water. The suspension was then sieved, with the aid of vacuum suction, through a stainless-steel mesh with the same characteristics of the HiPerDiF conveyer belt. The moist fibres were then scaled and placed under the HiPerDiF infrared heater and weighted every minute. The results of the water absorption-drying test are shown in Figure 2.

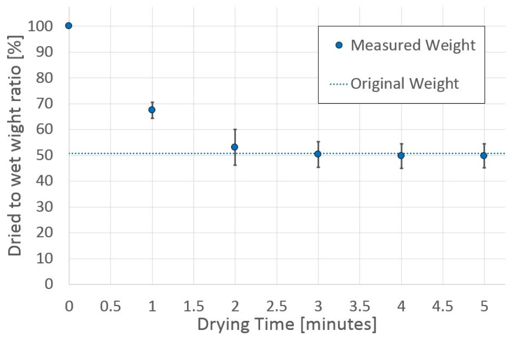

Figure 2: Water absorption-drying test results.

Observing Figure 2, it can be concluded that, after a drying time of about two minutes all the water absorbed by the fibres is extracted and the weight of the dried fibres is the same as the one before the dispersion in water.

3 TESTING METHODOLOGY

3.1 Tensile Test

To obtain the tensile test specimen shown in Figure 3, GFRP end-tabs were bonded with Huntsmann Araldite 2014-1. In the case of the tensile test specimens 4 layers of aligned discontinuous fibres were stacked to achieve a nominal thickness of 0.4 mm.

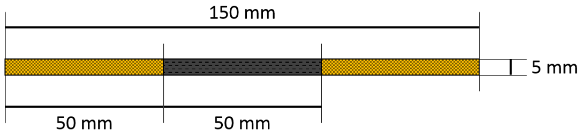

Figure 3: Tensile test specimen geometry.

The tensile tests were performed with an electro-mechanical testing machine at a cross-head displacement speed of 1 mm/min. The load was measured with a 10 kN load cell and the strain was measured with a video extensometer. A white speckle pattern over a black background was spray painted on the specimens to allow the strain measurement with the video extensometer.

3.2 Free Vibration Damping Test

The mode-one free-vibration test method with viscous modelling in a single degree of freedom configuration was used in this project for the calculation of the damping ratio. The test fixture was set-up accordingly to the ASTM E756 test standard. The clamping force at the root of the specimen was controlled through a torque wrench. The initial deflection, imposed manually, was kept within 10% of the free length (L). The dynamic response of the specimen was measured using a laser vibrometer (Polytec PDV-100) connected to a National Instruments DAQ system operated through LabView. For the free vibration damping test specimens 12 layers of aligned discontinuous fibres were stacked to achieve a nominal thickness of 1.2 mm.

4 RESULTS AND DISCUSSION

4.1 Flax Fibres Processing Trials Tensile Test

After establishing that the water absorbed by the flax fibre can be extracted after a suitable amount of time under an infrared heater, the effects of the drying time on the mechanical properties of pure flax fibres specimens have been investigated. Three sets of three specimens have been manufactured, two sets were dried for 5 and 1.5 minutes while the third was not subjected to any infrared radiation. Tensile tests were performed as described in Section 3.1, the results are shown in Figure 4.

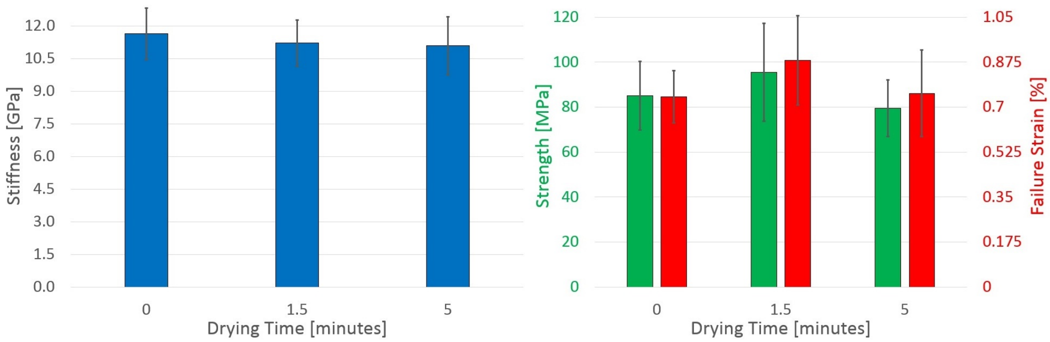

Figure 4: Drying time effect on 100% flax fibre specimen mechanical properties.

Observing Figure 4, it can be concluded that a high content of water in the fibres or an excessive drying time do not have a substantial effect on the cured material stiffness. However, both water absorption and excessive exposure to heat influence the strength properties of the material, this can be attribute to a reduced adhesion between fibre and matrix and to fibre damage. However, this test demonstrated that, with a careful selection of the fibres drying time, it is possible to use the HiPerDiF method to process flax fibres and seemingly other hydrophilic natural fibres.

4.2 Intermingled Flax/rCF Hybrid Composites Tensile Test

Four sets of three specimens, i.e. 75/25, 50/50, 25/75 % flax/rCF and a 100% rCF control set, have been manufactured to investigate the effect of the fibre content ratio on the mechanical properties of intermingled flax/rCF hybrid composites. The results of the tensile tests, performed as described in Section 3.1, are shown in Figure 5.

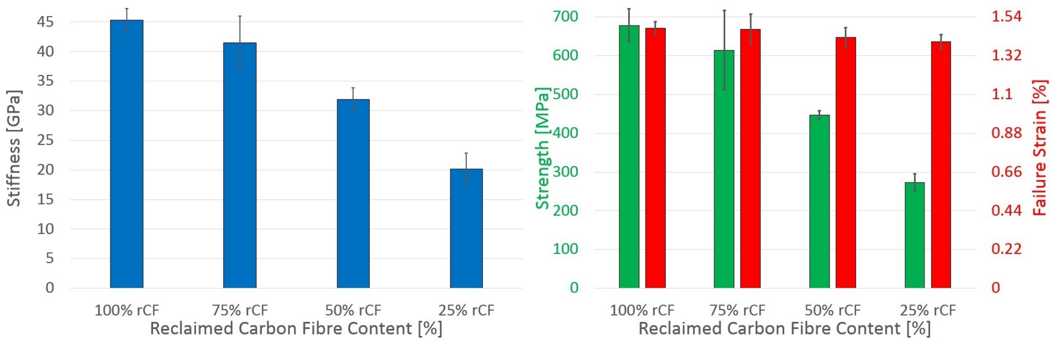

Figure 5: Intermingled flax/rCF hybrid composites tensile test results.

The stiffness and the strength of the material are directly related to the rCF content. However, the value of failure strain is almost constant (1.46±0.06%). Considering that the 100% flax fibre specimens fail at a strain of 0.88±0.17%, it can be concluded that the failure is primarily controlled by the rCFs that are carrying most of the load.

4.3 Intermingled Flax/rCF Hybrid Composites Free Vibration Damping Test

Four specimens with the same flax/rCF content as Section 4.2 have been tested with the methodology described in Section 3.2. Figure 6 shows the results of a round of tests performed with the same free vibration length.

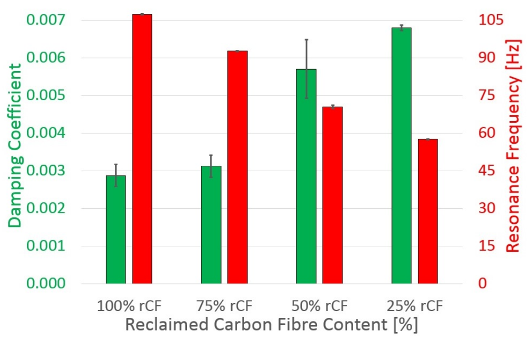

Figure 6: Free vibration damping test with the same free length.

The different resonance frequency can be explained considering that the affective thickness of the specimens varies between 1.59 for the 100% rCF specimen to 1.1 for the 75/25 % flax/rCF specimen.

A second round of test has been performed changing the specimen free length to have the same resonance frequency for all the four specimen types, as shown in Figure 7.

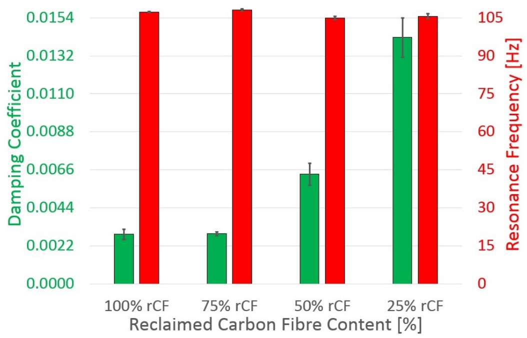

Figure 7: Free vibration damping test with the same resonance frequency.

In both cases the damping coefficient is directly related to the flax fibre content, with the 75/25 % flax/rCF specimen showing the highest damping coefficient.

5 CONCLUSIONS & FUTURE WORK

Figure 8 shows a summary of the main properties of the flax/rCF intermingled hybrid materials evaluated during this research work against the 100% rCF control material.

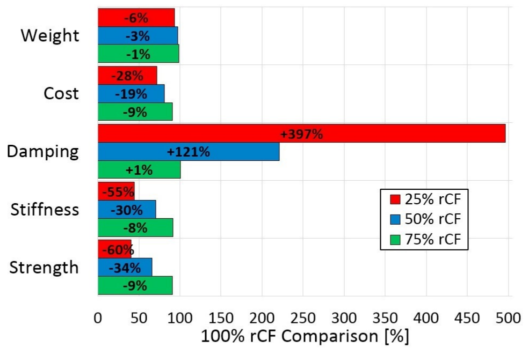

Figure 8: Comparison against 100% rCF specimens.

Flax/rCF intermingled hybrid materials manufactured with the HiPerDiF method can be a viable solution in applications where a reduction of primary properties, e.g. stiffness and strength, is an acceptable trade-off for the increase of secondary properties, e.g. damping, and cost reduction.

This work opens the possibility to further investigate the behaviour of flax/rCF hybrids. A first target will be to increase the fibre volume fraction above 50%. Moreover, the behaviour of intermingled hybrids different fibre length as well as the behaviour of interlaminated hybrids will be investigated. Finally, a campaign of more representative damping tests needs to be conducted.

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